Guided Transmission

Outline

- Introduction
- Physical Media of Connectivity
- Guided Transmission Media
  - Twisted pair
  - Coaxial cable
  - Optical fiber
- Wireless Transmission

Fundamental Limits on Channel Capacity

- Channel Capacity [C. Shannon, 1948]

$$C = W \log_2 (1 + S/N) \quad \text{bits / second,}$$

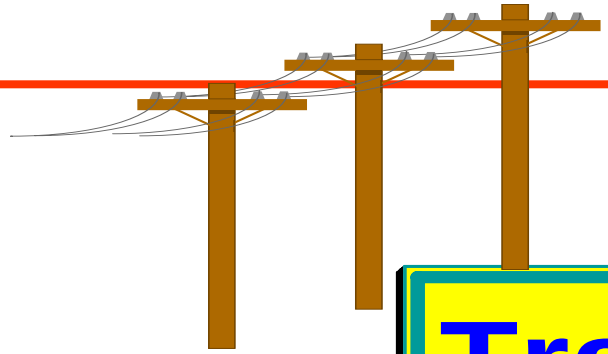
- where,
  - C channel capacity (bits/sec),
  - W bandwidth (Hz),
  - S average signal strength (Watts),
  - N noise power (Watts),
  - S, N at the receiver.

Fundamental Limits on Channel Capacity

- By encoding the transmission of information over a channel (Channel Coding) in the presence of “white” noise only, we can approach the Shannon's capacity limit, while (BER) P_e is bounded
- It can be proven that when the transmitted power is limited, then as M (number of symbols) increases, spacing between leves decreases, and thus, noise increases the probability of error at receiver.
- Practical systems use Error Control to provide error-free communication
  - ARQ
  - FEC

Overview of Physical Media

- Guided - wired
- Unguided - wireless
- Characteristics and quality determined by medium and signal
- For guided, the medium is more important
- For unguided, the bandwidth produced by the antenna is more important
- Key concerns are data rate and distance



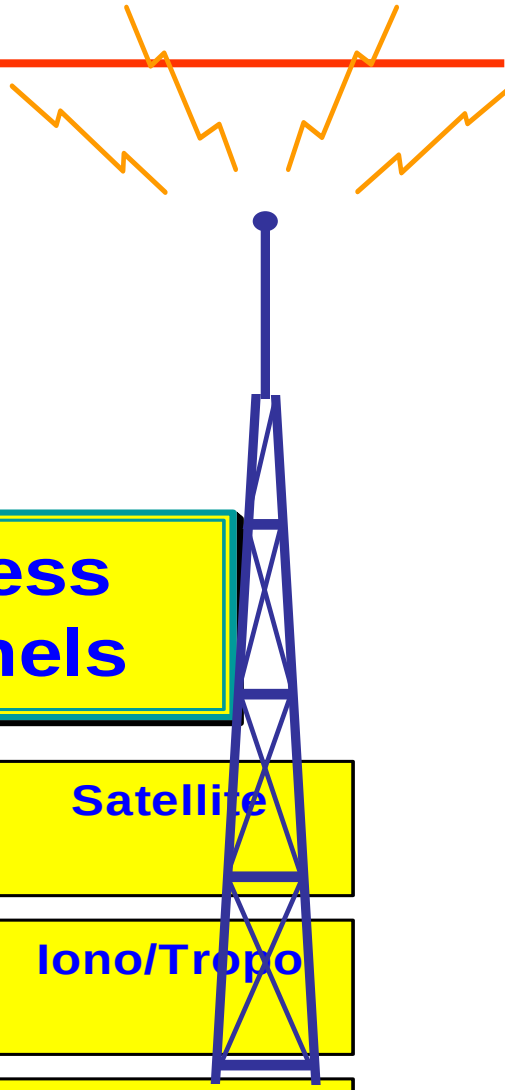
Transmission

Guided Transmission

- Wire pair
- Twisted pair
- Optical fiber
- Coaxial cable
- Submarine
- Waveguide

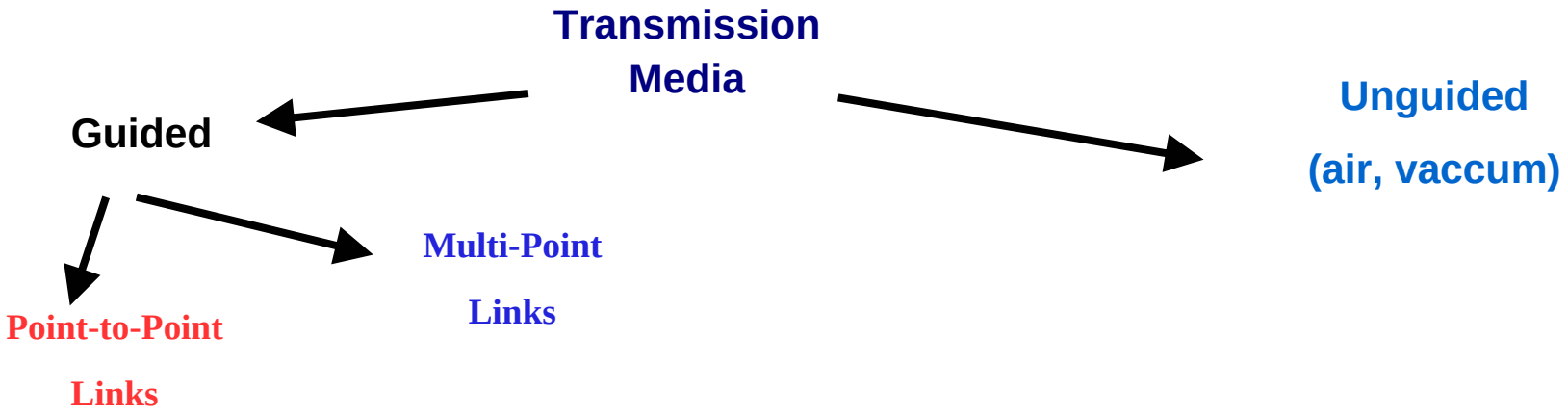
Wireless Channels

- MW Radio
- Satellite
- Mobile
- Iono/Tropo
- mmWave
- Optical



Transmission Media

- The *transmission medium* is the *physical path* between transmitter and receiver in a data transmission system.



- **Duplexity**
  - **Simplex**
    - **One direction only;**
  - **Half-duplex**
    - **Two directions, one at a time;**
  - **Full-duplex (duplex)**
    - **Two directions**

- **Direct link**
  - **No intermediate devices**
- **Point-to-point**
  - **Direct link**
  - **Only 2 devices share link**
- **Multi-point**
  - **More than two devices share the link**

Properties of Transmission Media

- A communication channel cosists of a transmiter, physical medium and receiver.
- The transmission medium is the physical medium the that conveys the signal's energy.
  - How the signals at various frequencies are treated by the medium
  - Attenuation $\rightarrow$ limit the distance of propagation
  - Noise is introduced in the medium and receiver.
- Characterization for Physical Media
  - Amplitude-Response $A(f)$, phase-shift $\phi(f)$ functions and bandwidth as functions of distance
  - Susceptibility to noise and interference

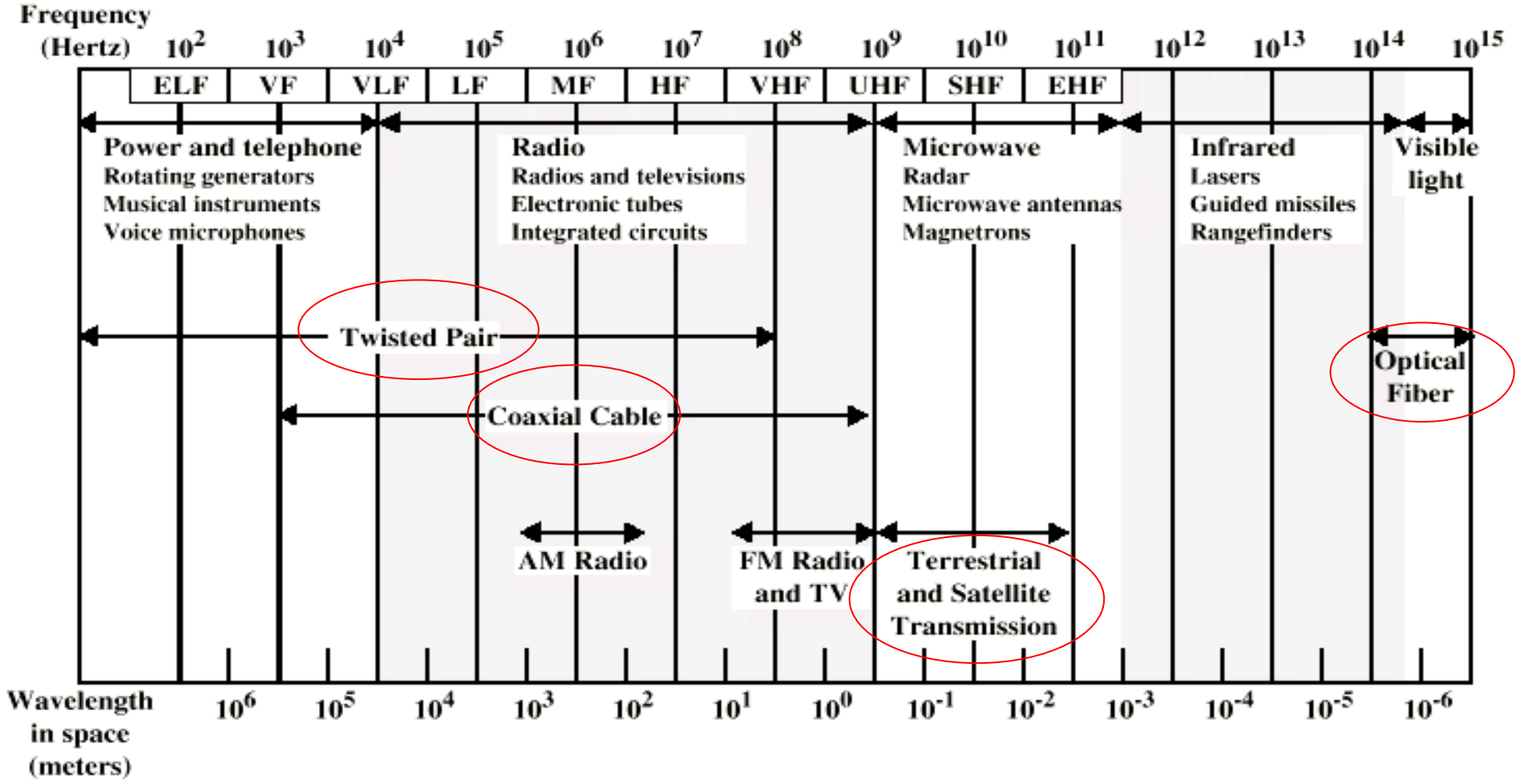
Design Factors for Transmission Media

- Bandwidth
  - Higher bandwidth $\rightarrow$ higher data rate (in general)
- Transmission impairments
  - Attenuation $\rightarrow$ limit the distance of propagation
- Interference
  - Distorts or completely wipe out signals
  - More important in unguided media
- Number of receivers (guided media)
  - More receivers atteched to medium (multi-point) introduce more attenuation

Design Factors for Transmission Media

- Propagation Velocity of Signal
  - A sinusoidal at f_0, propagates at $v = c / \sqrt{\varepsilon} f_0$ where, $c = 3\times10^8$, $\sqrt{\varepsilon}$ is the medium's dielectric constant (vacuum = 1)
- Attenuation: is a function of propagation distance
  - Wired media: 10^{kd} where, d distance, k constant depending on frequency
    - exponential in the distance
  - Wireless media: proportional to d^{n} where, d distance, n "path-loss exponent"
    - free space $n = 1$,
    - when obstructions are present $n > 2$.

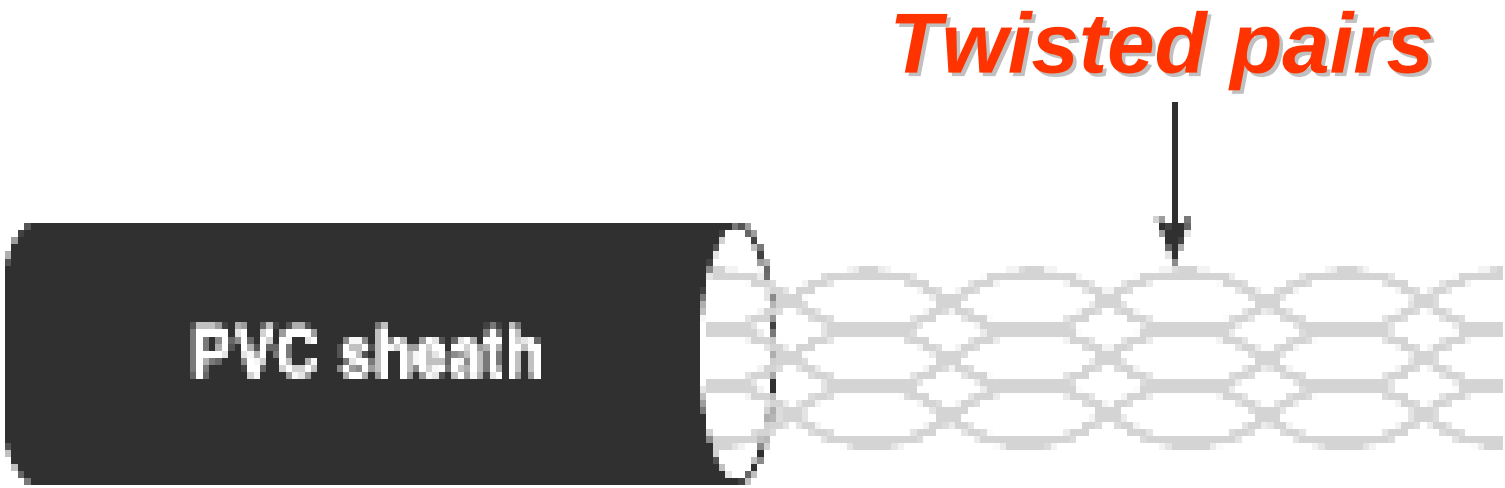
Electromagnetic Spectrum for Telecom



ELF = Extremely low frequency
VF = Voice frequency
VLF = Very low frequency
LF = Low frequency
MF = Medium frequency
HF = High frequency
VHF = Very high frequency
UHF = Ultrahigh frequency
SHF = Superhigh frequency
EHF = Extremely high frequency

Twisted Pair

- Twisted pair (TP) is the most common form of transmission medium in use today.
- Quite simply, TP is a pair of wires twisted together and combined to form a cable.
- The entire cable is usually surrounded with a tough PVC sheath to protect it from handling or its environment.
- TP is normally used to carry data at speeds from 10Mbps to 100Mbps, but the speed can be decreased by a number of error characteristics: data loss, crosstalk coupling, and electromagnetic interference (EMI).



Twisted pair cable

Category Specifications for TP

- The five major categories of TP cable are based on specifications designed by the Electronic Industries Association and the Telecommunications Industries Association (EIA/TIA).

- Please note that the EIA/TIA used only unshielded twisted pair (UTP) when it defined the standard wiring categories for twisted-pair cables.

- Category 1
- Category 1 wiring is mainly used to carry voice. The CAT 1 standard was used primarily for telephone wiring prior to the early 1980s. Category 1 is not certified to carry data of any type and, in most cases, is not implemented as a cable type for data-grade wiring.

- Category 2

  Is used to carry data at rates up to 4Mbps. This type of wiring is popular for older token-based networks utilizing the 4Mbps specification of the token-passing protocol. It is rated to 1MHz.

- Category 3

  Is also known as voice-grade cable. It is used primarily in older Ethernet 10base-T LANs and is certified to carry data at 10Mbps. It is rated to 16MHz.

- Category 4

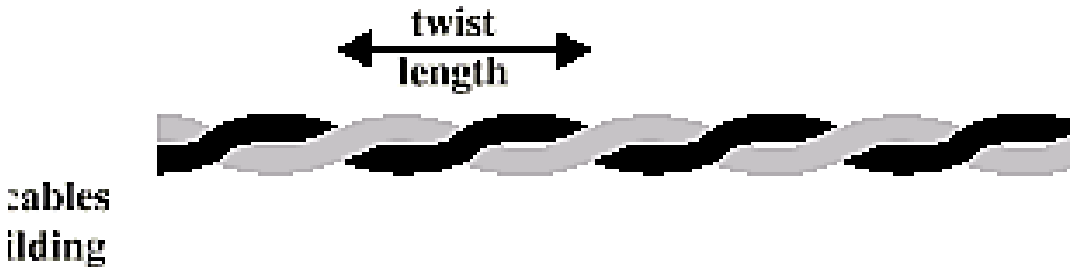
  Is used primarily when implementing token-based or 10base-T/100base-T networks. CAT4 is certified at 16Mbps and consists of four twisted wires. It is rated to 20MHz.

- Category 5

  is the most popular Ethernet cabling category. It is capable of carrying data at rates up to 100Mbps and is used for 100base-T and 10base-T networks. It is rated to 100MHz.

- **TP is merely copper wires twisted in a spiral along the length of the cable.**
- **Two types of TP exist: unshielded and shielded.**
- **There are five major categories of TP cable wiring.**

The Venerable Twisted Pair



- Twisted Pair Cable
  - Two parallel insulated copper wires (signal, ground reference)
  - Wires are twisted regularly around each other, and often combined with others into a cable
  - Receiver detects information signal by the voltage difference in two wires.
  - Interference is picked up by both wires, thus their difference will remain unaffected.
  - Twisting reduces interference among adjacent pairs.
  - Twist: 5—15cm
  - Thinkness: 0.4—0.9mm

Twisted Pair – Transmission Characteristics/Rates

- TPs can pass a wide range of frequencies
- Attenuation is measured in dB/mile
  - 1–4 dB/mile at 1KHz
  - 10–20 dB/mile at 500KHz
- Analog Transmission
  - Amplifiers every 5km to 6km
  - Bandwidth: 1MHz (point-to-point links)
- Digital Transmission
  - Either analog or digital signals
  - Repeaters every 2–3km
  - Long distances: few Mbs; Short distances: 100 Mbs–1GBs
  - A 24-gauge TP (diameter 0.016 in)

Type	Distance (km)	Data Rate (MBs)
T-1	5.5	1.544
DS2	3.7	6.312
¼ STS-1	1.4	12.96
½ STS-1	0.9	25.92
STS-1	0.3	51.84

Attenuation in Twisted Pair

- ***Attenuation/mile vs. frequency in twisted pair.***
- ***Attenuation is strongly correlated to frequency***

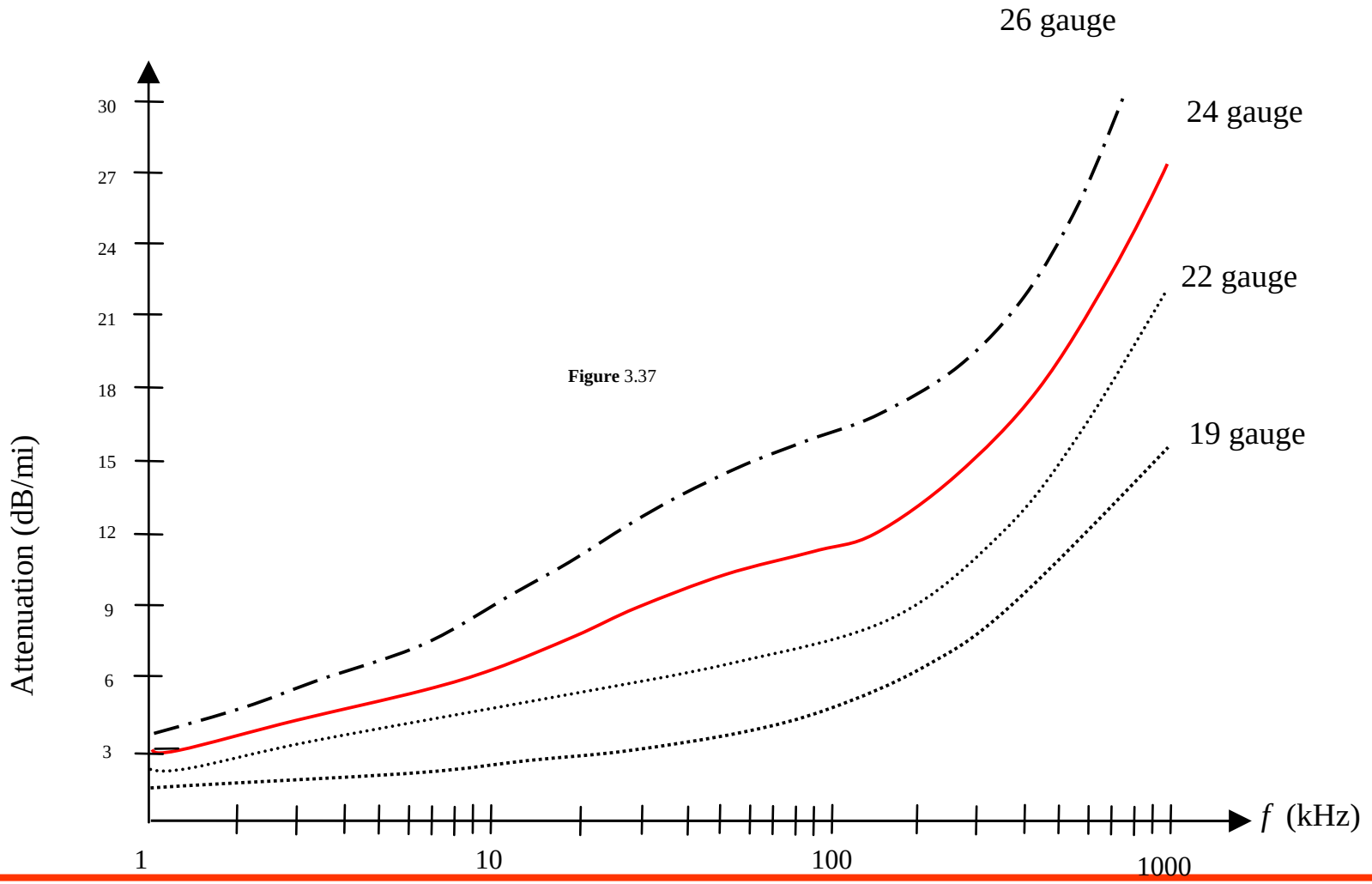


Figure 3.37

Unshielded and Shielded Twisted Pair

- Unshielded Twisted Pair (UTP)
  - Ordinary telephone wire
  - Cheapest
  - Easiest to install
  - Suffers from external EM interference
- Shielded Twisted Pair (STP)
  - Metal braid or sheathing that reduces interference
  - More expensive
  - Harder to handle (thick, heavy)

Twisted Pair - Applications

- Most common, easy to handle medium
- Telephone Network (designed for 0-4KHz Voice channels)
  - *subscriber loop*: the bulk of access networks between house and local exchange
    - crucial for evolution of digital networks;
    - loading coils reduce bandwidth to 3KHz
  - *trunk plant* : often between central offices ;
    - being replaced by optical fiber
  - data rate is approximately 40Kbs
- Within buildings
  - To private branch exchange (PBX)
- For local area networks (LAN)

TP – Applications: Digital Subsriber Loops (DSL)

- ISDN over Telephone Network
  - two bearer (B) channels at 64Kbs and one data at 16KBs
  - never widely deployed.
- Asymmetric Digital Subsrciber Line (ADSL) for higher rates
  - use the same access network (*subscriber loop TP*)
  - no loading coils
  - frequency spectrum is split into two parts:
    - upstream (user to net): 64 – 640 Kbs
    - downstream (net to user): 1.536 – 6.144 Mbs
  - ITU-T G.992.1 for ADSL uses Discrete Multitone (DMT)
    - DMT splits bandwitdth into a number of sub-channels
    - information is sent simultaneously to all sub-channels using QAM
    - it avoids poor quality sub-channels

TP – Applications: Local Area Networks

- TP wires are installed in all buildings
- Wire lengths < 100m
- Good candidate for LANs
  - Category 3 UTP: voice grade, good for speeds up to 16 Mbs
  - Category 5 UTP: good for speeds up to 100 Mbs
  - Shielded TP: better signal quality, more expensive
  - Computers are attached to a hub (multiport RR) in star topology or to LAN switch (multiport bridge)
- 10BASE-T: Ethernet, 10 Mbs, baseband transmission
  - 2 Cat-3 UTP cables for bi-directional connection to hub
  - Manchester line coding
- 100BASE-T: Ethernet, 100 Mbs, baseband transmission
  - 100BASE-T4: 4 Cat-3 wires: 3 at 33 1/3Mbs; 1 for collision detection
    - half-duplex; ternary line code
  - 100BASE-TX: 2 Cat-5, bi-directional at 125Mpulse/sec

Twisted Pair - Pros and Cons

- Pros
  - Cheap
  - Easy to work with
- Cons
  - Limited distance
  - Limited bandwidth (1MHz)
  - Limited data rate (100Mbs)
  - Susceptible to interference and noise

Coaxial Cable

- Coaxial cable, named from the two cable axes that run the length of the wire, is a versatile and useful transmission medium.
- The cable consists of a solid or braided outer conductor surrounding either a solid or a stranded inner conductor.
- The conductors are usually separated by a dielectric material, and the entire wire is covered with an insulating jacket.
- Coaxial wire allows for greater shielding from interference and greater segment distances.
- Coaxial 10base-5/2 has a transmission rate of 10Mbps. 10base-5 has a maximum segment length of about 500m/segment, whereas 10base-2 is about 180m/segment.

Coaxial Cable

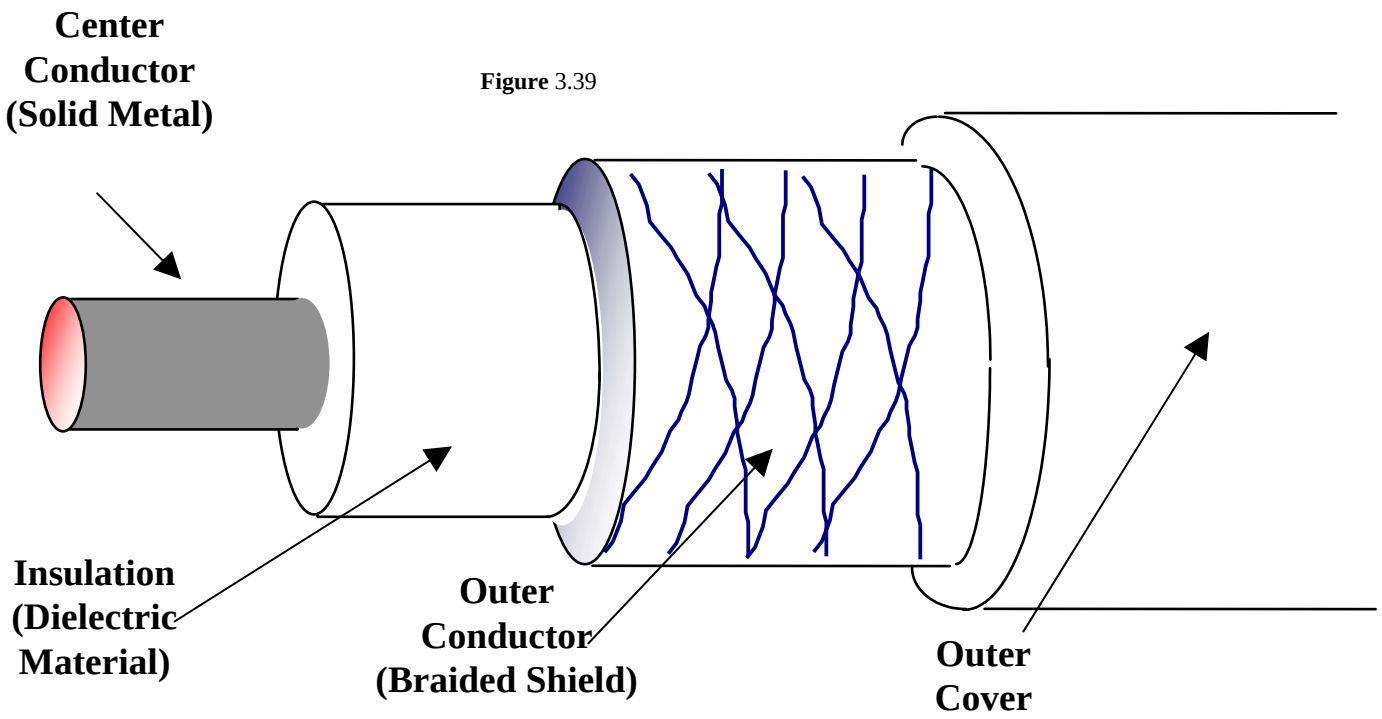


Figure 3.39

- Construction of CC allows it to operate over wider range frequencies than TP
  - Diameter 1–2.5cm;
  - Longer distances than TP;
  - More attached stations.

- **It has better noise immunity than TP.**
- **It consists of two pipes separated by dielectric material.**
- **It comes in two types: 75-ohm (1/2") and 50-ohm (3/8").**

Here are some points to remember about fiber cable:

- **It's immune to EMI.**
- **Transmission distances up to 10km are possible.**
- **Up to 4Gbps has been demonstrated in a laboratory.**
- **Either LED or ILD light sources can be used.**

Coaxial Cable – Transmission Characteristics

- Less susceptible to interference
- Constraints
  - Attenuation, thermal noise, intermodulation noise (FDM).
- Analog
  - Amplifiers every few km; closer for higher frequencies
  - Up to 500MHz (cable TV)
- Digital
  - Repeater every 1km; closer for higher data rates
  - 8.448–564.992Mbs (backbone telephone links)

Attenuation in Coaxial Cables

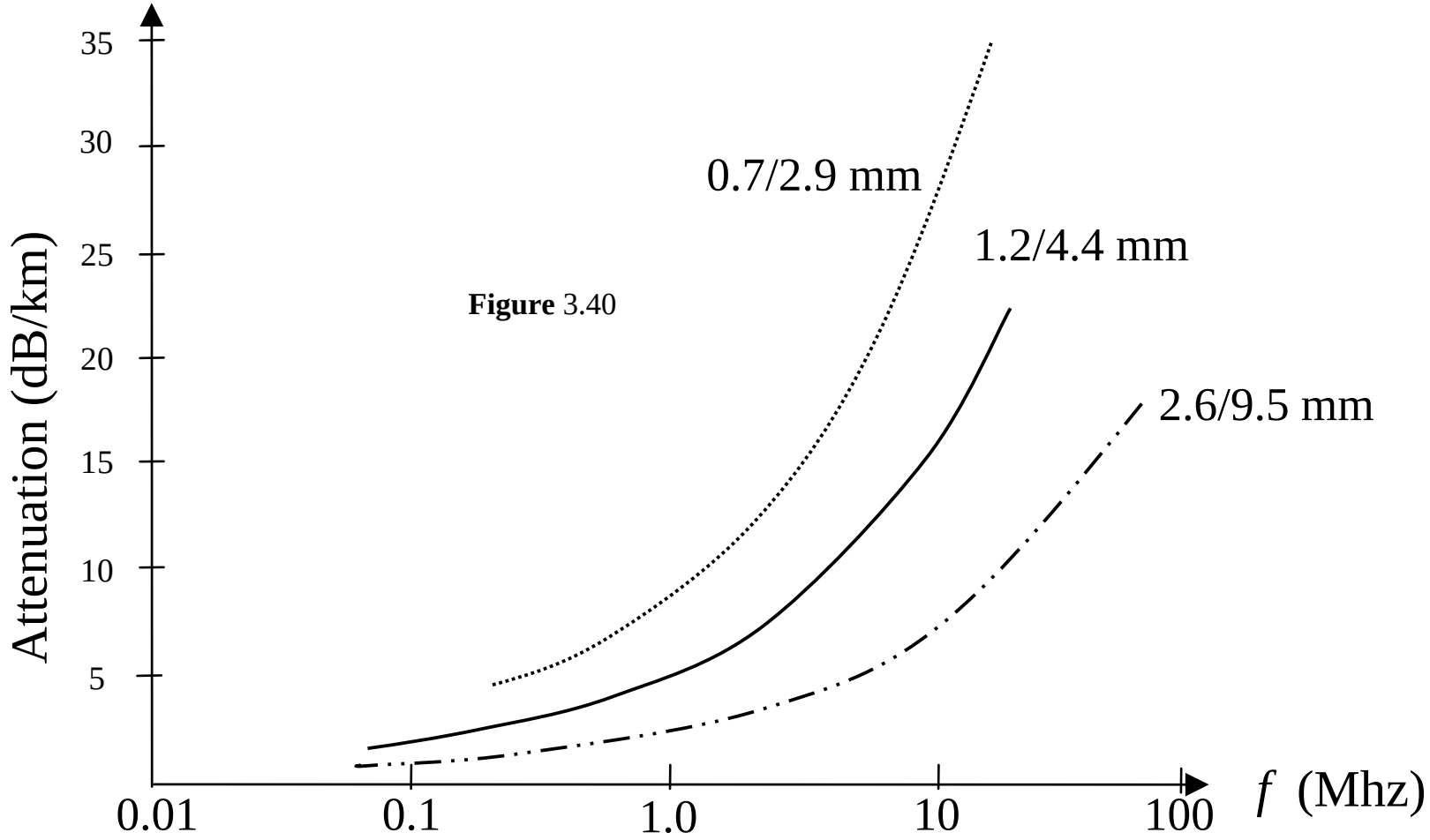


Figure 3.40

Coaxial Cable Applications

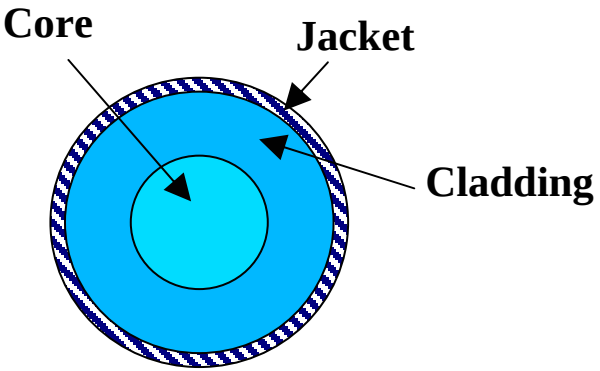
- Most versatile medium
- Television distribution
  - 6–8MHz / (NTSC/PAL) channel; 50–70 channels;
  - Cable TV
- Long distance telephone transmission
  - Can carry 10,000 voice calls simultaneously
  - Being replaced by fiber optic
- Short distance computer systems links
- Local area networks
  - Baseband (Ethernet)
  - Broadband

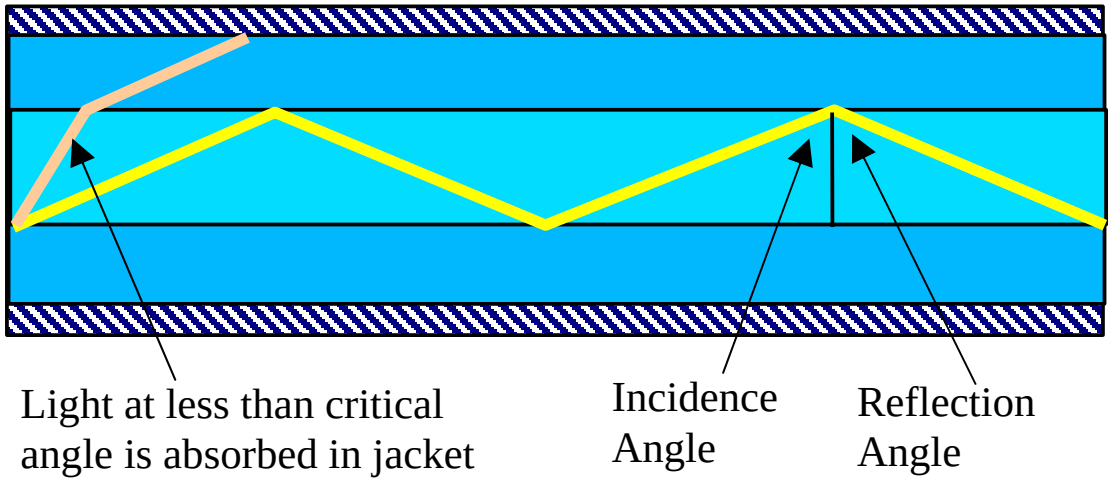
Application: Ethernet LANs

- Original Ethernet LAN design was based on coaxial cables
  - Digital Transmission, Baseband Signals
  - Thik-coaxial (10BASE5), 10mm cable; 10Mbps; 500m/segment;
  - Thin-coaxial (10BASE2), 2mm cable; 10Mbps; 185m/segment;
  - Regenerative Repeaters are used to allow longer distances;

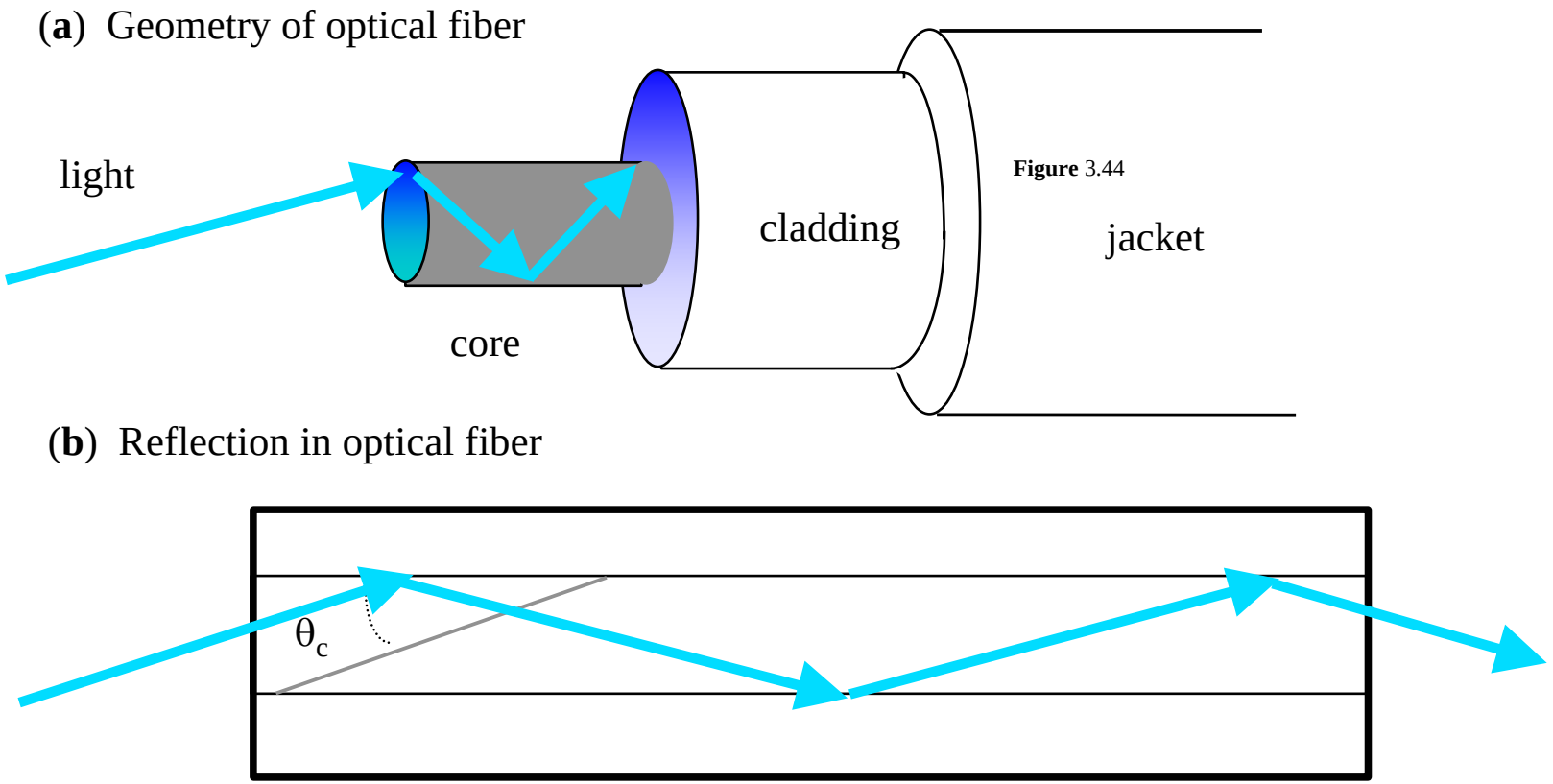
Optical Fiber – Geometry

- Very High Bandwidth
- Glass or plastic core
- Specially designed jacket





Optical Fiber – Transmission of Light



- Transmission of light waves in optical fiber
  - Core has slightly higher optical density (refraction index) than cladding
  - Ratio of refraction indices define critical angle θ_c
  - When incidence angle < θ_c light is reflected back into the core

Optical Fiber – Transmission System

- Electrical signal modulates light of certain wavelength into pulses
  - Light Emitting Diode (LED)
    - •cheaper; wider operating temp range; last longer
  - Injection Laser Diode (ILD)
    - •more efficient; greater data rate
- ON/OFF Keying is used
  - Light-Pulse 1
  - No Light 0
- Optical detector converts light into electrical signal

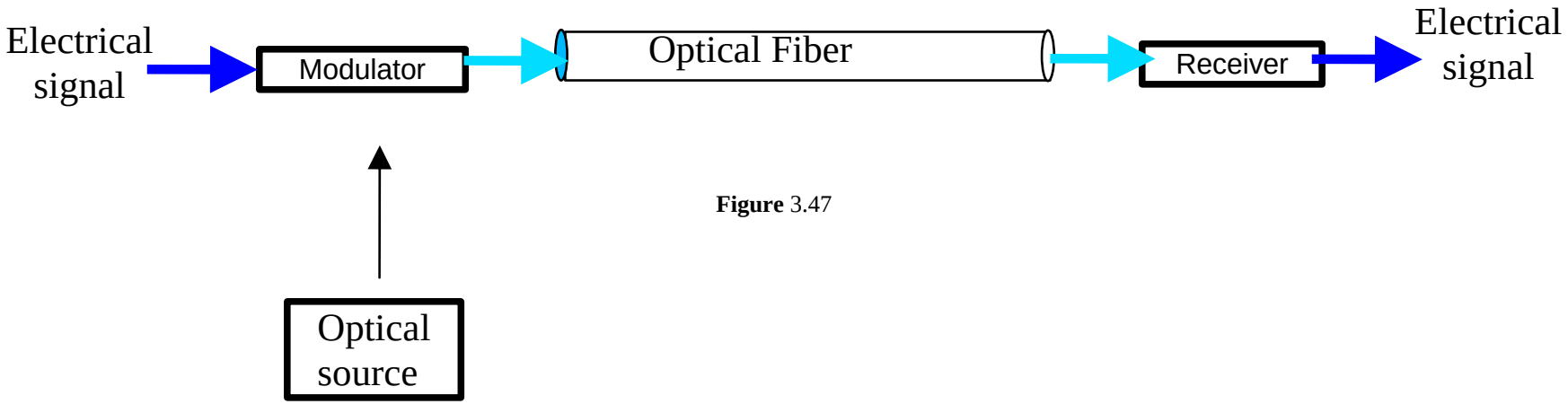


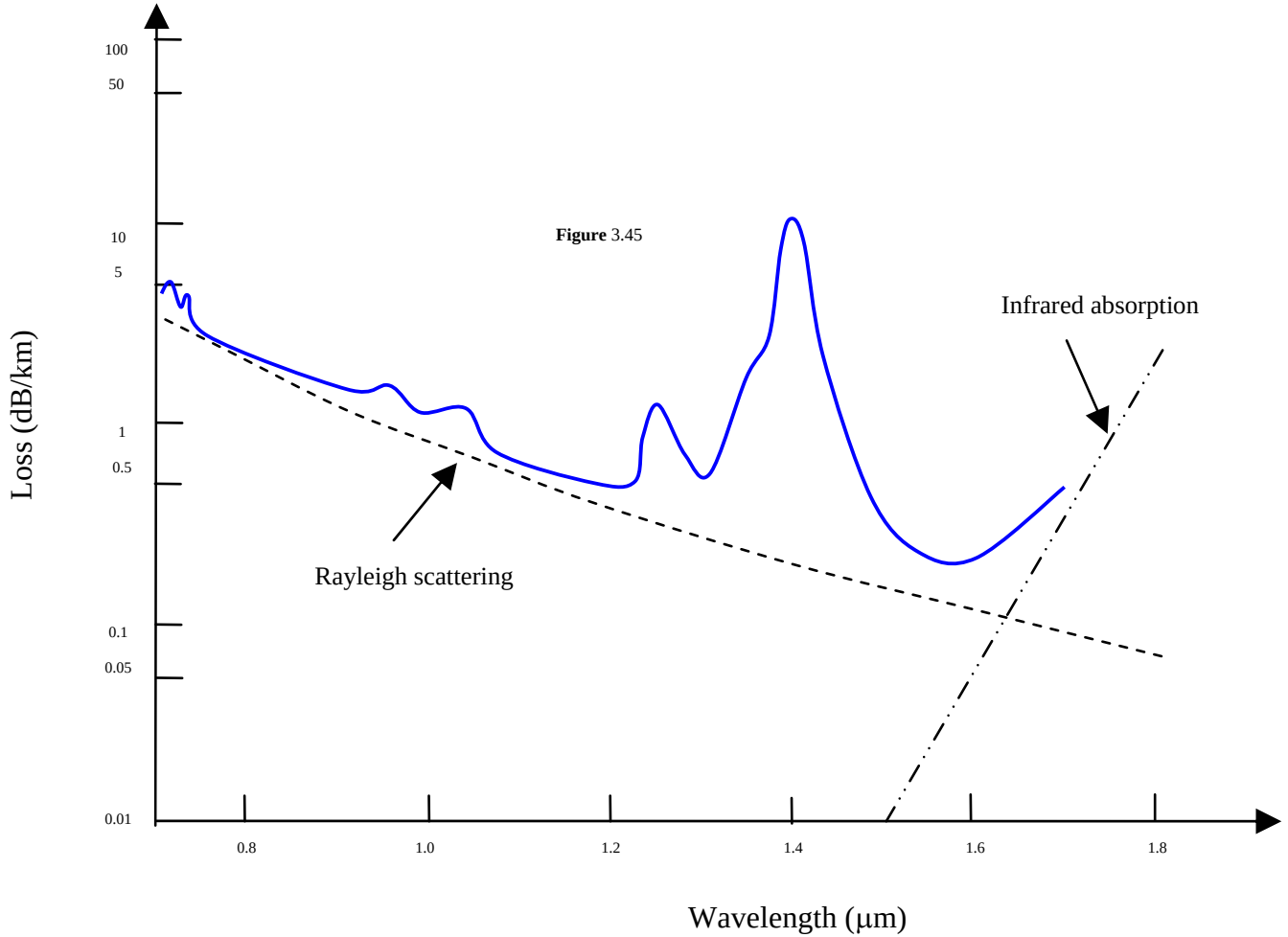
Figure 3.47

Optical Fiber – Transmission Characteristics

- Act as wave guide for 10^{14} to 10^{15} Hz
  - Portions of infrared and visible spectrum
- Region around 1300nm
  - attenuation < 0.5dB / km
  - bandwidth 25Terahertz !
- Region around 1550nm
  - attenuation < 0.2dB / km
  - bandwidth 25THz
- Wavelength Division Multiplexing (WDM) attempts to utilize BW
  - Dense WDM: 160 wavelengths at 10 Gps each
  - Early WDM: 16 wavelengths at 2.5 Gps each; 300km
- As light pulse propagates it spreads (flattens)
  - Solitons: special pulses that maintain their shape
  - 80 Gps over 10,000km possible with solitons

Optical Fiber – Attenuation

- Attenuation *vs*. wavelength for optical fiber.



Modes in Optical Fiber

(**a**) **Multimode** fiber: multiple rays follow different paths

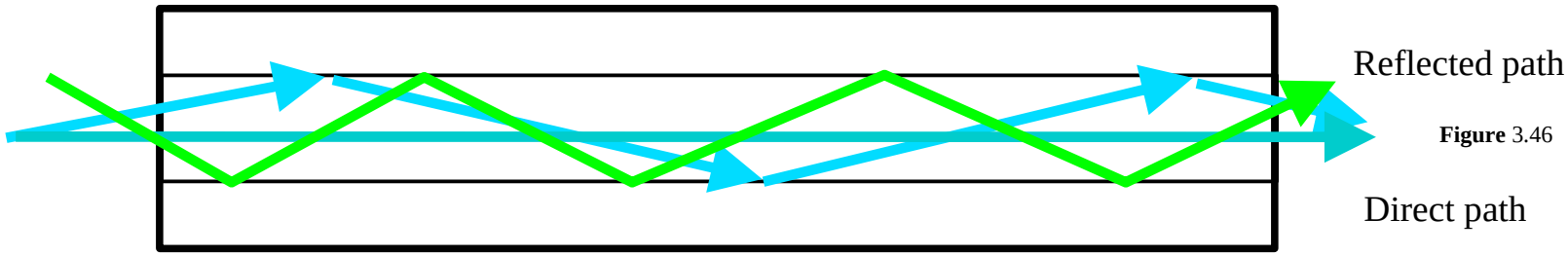
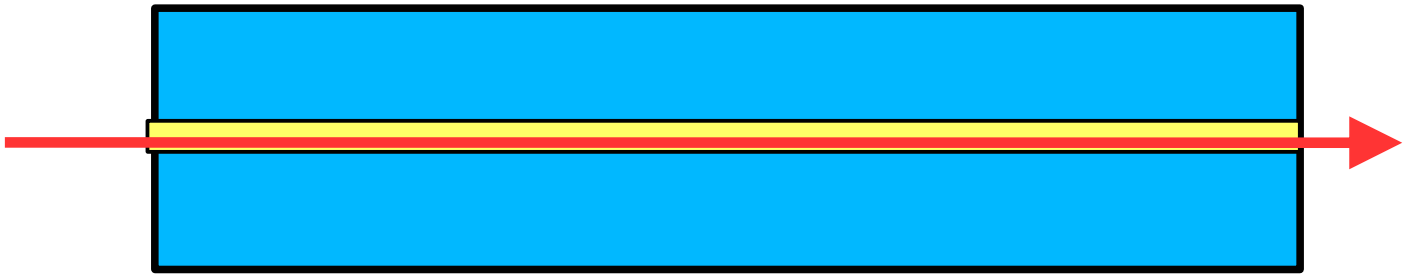


Figure 3.46

(**b**) **Single** mode: only direct path propagates in fiber



- Multi-Mode Fiber (Step Index): multiple light rays at different angles
  - Limitiations in the data rate.
- Single-Mode: very small core permits straight path propagation
  - Longer distances, higher data rates

Optical Fiber - Applications

- Natural choice of medium for backbone in Wide-Area Networks
  - TDM of hierarchy of electrical and optical signals
  - Long-haul, metropolitan, rural exchange trunks
  - 45 Mps to 9.6 Gbps (single wavelength);
  - 40 Gps to 1600 Gps (WDM)
  - Has started finding use in access networks
    - Subscriber loops (“fiber to home”) but cost is too high
    - Fiber to curb is less costly
- LANs with high bandwidth requirements.
  - Ethernet (10, 100, 1000, 10000 Mbs)
    - 10BASE-FP
    - 100BASE-FX
    - 1000BASE-X (-SX 850nm, -LX 1300nm)
  - FDDI (100 Mbs),
  - ATM.

Optical Fiber - Benefits

- Much Greater Capacity
  - Data rates of 1000s of Gbps
- Smaller size & weight
- Lower attenuation
- Electromagnetic isolation
- Greater repeater spacing
  - 10s of km at least

Table 2.1 Physical media comparison chart

Medium	*Advantages*	*Disadvantages*
TP	Low cost, easy to install	not secure, worst noise immunity
COAX	Relatively fast on short runs	not secure, poor noise immunity
Fiber	Voice, data and video, fast, long distance	difficult to install, limited to point-to-point, expensive

Wireless Transmission

- Unguided media (vacuum, air)
- Transmission and reception via antenna
- Directional
  - Focused beam
  - Careful alignment required
- Omnidirectional
  - Signal spreads in all directions
  - Can be received by many antennae
  - Natural broadcast transmission

Frequency Bands

- 2GHz – 40GHz
  - Microwave
  - Highly directional
  - Point to point
  - Satellite
- 30MHz – 1GHz
  - Line-of-Sight (LoS) propagation
  - Omnidirectional
  - Broadcast radio
- 2MHz – 30MHz
  - Sky-Wave Propagation (Ionosphere reflection)
- Below 2MHz
  - Ground-Wave Propagation (follows Earth's surface)
- 3×10^{11} to 2×10^{14}
  - Infrared
  - Local

Wireless LANs and Bluetooth

- Wireless LANs is application of omnidirectional wireless transmission.
- US: ISM bands for unlicensed communication (interference among groups)
- Europe: HIPERPLAN at 20Mbs [5.15-5.3GHz]
- US: FCC [5.15-5.35GHz] and [5.725-5.825GHz] a 350MHz spectrum for LANs.
- Bluetooth is a wireless standard designed for high-speed, short distance communication [2.45 GHz]
  - Developed by Ericsson, Nokia, IBM, Toshiba, and Intel
  - Is envisioned to eliminate wires in the office.
  - Connects PDAs, 3G phones, laptops, projectors, printers, workstations, home appliances, ...

Personal Wireless Communication

- Use a grid of towers to transmit signals
- AMPS (Advanced Mobile Phone System) [50-800MHz]
  - Older analog technology
  - Band split into 30KHz bands, each for one FM analog voice signal
- Digital: the clear alternative to analog trasmission
  - IS-54: Diff QAM replaces FM signal to support 3 users
  - IS-95: CDMA, direct seq., spread spectrum
- PCS (Personal Communication Services) [1.8-1.9Ghz]
  - low power transmitters cover microcells
  - combines cellular and cordless characteristics
- GMS (Global Mobile System) [900MHz band]
  - Digital standard in the rest of the world

Terrestrial Microwave

- Point-to-Point and Point-to-Multipoint Radio Systems
  - Highly directional antennas for μwave in 2-40Ghz
  - Parabolic dish, focused beam, Line of Sight (LoS)
- Inexpensive link between buildings
- Long haul digital telecommunications
  - 100Mbs : QAM with large signal constelation
  - Higher frequencies give higher data rates
- Logarithmic attenuation (vs. linear in metalic media) gives μwave radio an advantage
- Point-to-Multipoint wireless cable (28Ghz)
  - 1GHz bandwidth available
  - telephone office sends at 50Mbs to users within 5km
  - reflectors forward transmission to all subscribers
  - subscribers can send information upstream

Satellite Microwave

- Satellite is a relay station
  - Early systems with geostatonary satellite (at 35,784km)
- Satellite receives on one frequency (uplink), amplifies or repeats signal and transmits on another frequency (downlink)
- 15-20 transponders / satellite at 50Mbs/transponder
- Television
- Long distance telephone
- Private business networks
- Constellation of Low-Earth Orbit Satellites (LEOS) is planned
  - No geostationary orbit
  - Continuus Earth coverage
  - Participating satellites intercommunicate via high-speed links, forming a network

Emerging Satellite Networks (LEOS)

- ICO (10 satellites)
- Globalstar (48 satellites)
- Iiridium (66 satellites)
- Teledesic (288 satellites)

Broadcast Radio

- Omnidirectional
- FM radio
- UHF and VHF television
- Line of sight
- Suffers from multipath interference
  - Reflections

Infrared Light

- Modulate noncoherent infrared light
- Very Large Potential BW not yet exploited
- Being studied for very high-speed LANs
- Transmission contained within room
  - Line of sight (or reflection)
  - Blocked by walls
  - *e.g.*, TV remote control, IRD port
- Problem: Sun generates radiation in infra-red band
- IrDA Links
  - IrDA-C: 75Kbs up to 8meters; bi-directional, cordless keyboard, mice, joystick, handheld computers
  - IrDA-D: 115Kbs-4Mbs up to 1 meter;
  - Practical ?